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Structural Design of Large Future Wind Turbine Blades under Combined Loading

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ABSTRACT

The paper summarizes the design concept for very large wind turbine blades and review challenges which might be related to the upscaling of the blades to the length of 120 m. As the part of the initial study background data and the state of the art are briefly described. Later various design requirements and assumption are formed in order to define a geometrical outline for the 120 m long blade. Once the design criteria, geometry and aerodynamic properties of the blade are stated, the aeroelastic and structural analyses are the next step in the design process. This is requiring an interactive process usually conducted using numerical simulations. The application of combined load during structural analysis is discussed in order to provide realistic simulation of the operational and extreme load cases. The last part of the paper reviews the potential challenges expected during upscaling of the wind turbine blades.

KEYWORDS

Very Large Wind Turbines, Blade Design, Upscaling, Aeroelastic Analysis, Finite Element Analysis, Combined Loading.

1 INTRODUCTION

Issues as limited area of onshore sites in Europe, increasing demand for clean energy and the requirement of a higher energy output per turbine unit are currently the driving force in wind energy industry. Therefore the interest moves to the offshore wind turbines and wind farms. Thinking offshore, the environmental impact is lower, so it is the right region to take larger structures into consideration. The main motivation for increasing the size of wind turbines is that larger turbines have higher energy output per unit rotor area due to increased mean wind velocity with the height. The concentration of fewer but larger wind turbines on the most wind rich positions will be beneficial with respect to energy output, compared to a number of smaller turbines spread on larger and less favourable sites [1]. The purpose of

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the PhD project is to investigate, which structural and aeroelastic design challenges can be expected for blades of such a very large wind turbines. As offshore wind turbines are supposed to increase in size, the reference turbine for the project is expected to have a power output of 20 MW and the length of one blade to be 120 m.

2 THE DESIGN CONCEPT FOR 120 M BLADE

2.1 Background and state of the art

The optimal design of ever larger wind turbine blades is a constant challenge. The design process of blades for larger wind turbines is usually based on the approved concept of smaller blades. This approach can be in the case of very large blades inappropriate so innovative thinking is needed in this area. Integrated design is one of the current ideas how to improve the design process and performance of the rotor. Once the structural and aeroelastic analyses are considered at the same time, the iterative process is expected to bring significant results. However scaling of the current concepts is the first easy step to the better knowledge of the structure behaviour. Nowadays one of the biggest development intentions in the area of very large wind turbines is the EU project UpWind. The project looks towards the design of very large wind turbines (8-10MW), both onshore and offshore [2]. There is still a lot of discussion about various challenges and even feasibility of wind turbines of this size. Considering such enormous structure the crucial difficulties are expected in following areas: manufacturing, testing (replacement of the full scale test), transport, installation, operation and maintenance.

2.2 Design requirements and assumptions

Considering the future rotor blade to be twice longer than the longest one in these days, the challenges which were not important in the smaller scale become critical. Apposite examples are the wind shear and effect of Reynolds number changes, which have to be considered when talking about 120 m long blade, nearly 360 m tip height (the highest point of the rotor). As the reference turbine is expected to be placed offshore, the effect of the wave load and its combination with other loads should not be neglected. The development of the rotor blades in recent years shows that the blades became slender a more flexible. This tendency leads to intentionally prebended blades to prevent the tower collision during the operation. In this case the large displacement at the tip of the blade leads to the non linear effects that have to be considered during analyses. The fatigue caused by increase in the weight of the blade, and thus selfweight loads, is expected to be one of the essential issues of very large blade design. Materials as carbon, wood or bamboo could be employed to decrease the weight, as well as new concepts of the blade structure. Significant weight reduction together with increased buckling capacity offers for example use of new sandwich elements in the primary structure of large wind turbines (main spar), more details in [1].

2.3 Structural and aeroelastic analyses

The structural analysis of the wind turbine blades is currently often performed using finite element method. As the blade structure is very complex due to the use of composite and sandwich materials and limited computational capacity, various concepts and simplification are used. The blade is usually modelled by layered shell, layered solid or combination of these elements. As the layered shell elements are inaccurate with respect to torsional stiffness determination and shear stress due to torsional loading, layred solid elements are recommended for more accurate models [4]. Next step to the detailed structural analysis is the sophisticated application of the real loads to the model. The global and local behaviour of the model should be validated over experimental results to ensure obtained response corresponds to the reality. The finite element model is generally too detailed, so the multibody based formulation is one of the possibilities of aeroelastic analysis of the wind turbine. The aeroelastic code HAWC2 developed at Risø DTU considers the blades and other parts of wind turbine as a finite number of 3D Timoshenko beam elements. These beam elements must accurately represent all of the mechanical properties of the full blade. The constitutive matrix can be obtained by the Beam Property Extraction Method [5] that determines displacements and rotations of each beam element by applying six different load cases.

2.4 Combined load

The wind turbine blade is loaded by three types of loads: aerodynamic load caused by wind field, the inertial load due to blades acceleration or deceleration and the sinusoidal gravitational load which acts with frequency corresponding to the rotation of the wind turbine and thus increases the fatigue loading. Nowadays the blades are mostly only tested for two separate load cases, flapwise and edgewise bending. The application of combined load during the tests is expected to improve the simulation of the real operational and extreme loads. The FE modelling can be improved by use of more advanced methods of applying the aerodynamic loading (pressure distribution over full model) instead of the simplified load application (lift and drag force on each cross-section). The loads are than applied in a manner which accurately simulates the way loads are applied in operation. Generally is expected that new load cases may become important when the blades grow in size and flexibility.

3 CONCLUSIONS

As initial step of the PhD project study on changes in aeroelastic and structural behaviour of the wind turbine blade when scaled from 34 m to 120 m length is going to be performed. As the design concept will remain the same, some issues are expected to be critical. The gravitational load increases cubically with the rotor diameter, the large composite and sandwich panels are more sensitive to buckling, profile changes during operation could significantly influence the energy output and flutter will need to be considered.

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